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(54) Method and apparatus for channel equalization in wavelength division multiplexed systems

(57) A method and apparatus for channel performance equalization in wavelength division multiplexed (WDM) systems is disclosed. Performance of the channels is estimated from optical power measurements of each signal transmitted by the channels. The measurements are taken at the inputs of optical amplifiers in the transmission path of the system. The channels are equalized by adjusting the optical power of the channel transmitters. The method is applicable to point-to-point networks as well as more complex network configurations such as those having an add-drop multiplexer (ADM) for inserting and extracting channels from the transmission path. The method can compensate for signals having different bit rates by applying an offset to the amount of optical power adjustment of the channel transmitters. Furthermore, if different types of optical amplifiers are used in the transmission path, the method can accommodate different noise characteristics of the amplifiers by using their noise figures in determining the amount of optical power adjustment of the transmitters that is required to equalize channel performance.

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Description

Field of the Invention

[0001] This invention relates to optical transmission systems and more particularly to channel performance equalization in wavelength division multiplexed systems.

Background of the Invention

[0002] Wavelength division multiplexing (WDM) is a technique employed in high capacity optical transmission networks to increase their information carrying capacity. WDM systems transmit a plurality of channels, each at a different wavelength, over a single optical fiber. Typically, a WDM system comprises N optical transmitters for optically transmitting N channels of information, a wavelength multiplexer for combining the N channels on one optical fiber, optical amplifiers connected in series by optical fiber cable, a wavelength demultiplexer for separating the optical signal into N channels, and N receivers for detecting the information carried by the N channels. In network configurations having an add-drop multiplexer, the multiplexer is located at a position along the path of the serially connected amplifiers. The add-drop multiplexer is capable of extracting a channel from the network for directing it to an alternative receiver and may also insert into the network a new channel transmitted at the same wavelength as the extracted channel.

[0003] Performance of WDM systems is related to the optical signal to noise ratio (OSNR) at the receiver. Due to wavelength dependent gain profiles, noise profiles and saturation characteristics of the optical amplifiers and wavelength dependent gain of other components in the optical path, channel OSNR values at the receiver will be unequal for equal transmitter optical power levels.

[0004] In U.S. Pat. No. 5,225,922 Chraplyvy et al disclose a method of equalizing channel performance in point-to-point WDM systems using the optical power levcl of each channel transmitter and the OSNR measured at each channel receiver. New transmitter optical power levels for each channel are calculated from the optical power level and OSNR values using a specified formula. The channel transmitters are then set to the new optical power levels. This process is repeated until the difference between the channel OSNRs is within a predetermined range. Although this method can equalize the OSNR at the receivers within a few iterations, it requires the use of expensive instruments such as an optical spectrum analyzer to measure the OSNRs at the receivers. A further disadvantage of this method is that it is not easily adaptable to more complex optical network configurations such as those having an add-drop multiplexer.

[0005] It appears that it would be advantageous to provide a less expensive and more flexible method of equalizing channel performance in WDM systems that is capable of equalizing performance in more complex networks such as those having an add-drop multiplexer.

Summary of the Invention

[0006] It is an object of the present invention to provide improved method and apparatus for channel equalization in WDM systems that reduce or overcome some or all of the disadvantages of the techniques described above.

[0007] In accordance with one aspect of present invention there is provided a method of equalizing the performance of a first channel transmitting a first signal from a first transmitter along a first transmission path with respect to the performance a second channel transmitting a second signal from a second transmitter along a second transmission path, the equalization being effective at a predetermined location in an optical wavelength division multiplexed system and the location being downstream of an optical amplifier in the first path and downstream of an optical amplifier in the second path, the method comprising the steps of measuring the optical power of the first signal and the second signal at the inputs of each optical amplifier that is upstream of said location, and adjusting the optical power of the first transmitter by an amount dependent upon the sum of the reciprocal of the first signal optical power measurements relative to the sum of the reciprocal of the second signal optical power measurements.

[0008] An advantage of this aspect of the invention is that it provides a method for equalizing channels at a chosen location in a WDM system based on signal optical power measurements which may be taken with less expensive measurement apparatus than those used for channel equalization in known methods. Another advantage is that the method may be used for equalizing channel performance in a WDM system having a complex network configuration such as one having an add-drop multiplexer. Furthermore, the method may be performed dynamically and may therefore be responsive to changes in channel performance that could for example be due to changes in the WDM system caused by fault conditions or by network reconfiguration.

[0009] Conveniently the step of adjusting the optical power of the first transmitter includes first adding an offset to the amount of transmitter adjustment to obtain a resultant amount of transmitter adjustment and then adjusting the optical power of the first transmitter by the resultant amount, the offset being dependent upon the difference between the bit rate of the first signal and the second signal. Applying an offset to the amount of transmitter adjustment in this

way has the advantage of providing better channel equalization by compensating for different noise bandwidths resulting from different bit rates of the signals.

[0010] Conveniently the step of adjusting the optical power of the first transmitter includes predefining a noise figure for each of the optical amplifiers and adjusting the first transmitter by an amount in dependence upon the sum of the reciprocal products of the noise figure and the respective optical power measurement for each optical amplifier along the paths. Predefining a noise figure for each of the optical amplifiers has the advantage of providing better channel equalization by compensating for different noise characteristics of the optical amplifiers along the transmission paths of the signals being equalized.

[0011] In accordance with another aspect of the present invention there is provided an apparatus for equalizing the performance of a first channel transmitting a first signal from a first transmitter along a first transmission path with respect to the performance a second channel transmitting a second signal from a second transmitter along a second transmission path, the equalization being effective at a predetermined location in an optical wavelength division multiplexed system and the location being downstream of an optical amplifier in the first path and downstream of an optical amplifier in the second path, the apparatus comprising a receiving means for receiving optical power measurements of said signals taken at the inputs of each optical amplifier that is upstream of said location, a storing means for storing the optical power measurements, a calculating means for calculating an amount of transmitter optical power adjustment of the first transmitter from the optical power measurements and a communicating means for communicating the amount of transmitter optical power adjustment to the first transmitter.

Brief Description of Drawings

[0012] The invention will be further understood from the following description with reference to the attached drawings wherein:

FIG. 1 is a block diagram of a WDM system in accordance with an embodiment of the present invention;
FIG. 2 is a graph of an example of the optical spectrum at the receiver terminal of FIG. 1
FIG. 3 is a block diagram of a WDM system with an add-drop multiplexer in accordance with another embodiment of the present invention.
FIG 4. is a block diagram of a WDM system with an alternate add-drop multiplexer configuration in accordance with another embodiment of the present invention.

Detailed Description of the Invention

[0013] FIG. 1 is a block diagram of a WDM system **10** according to an embodiment of the present invention. The WDM system comprises a transmitter terminal **12**, a receiver terminal **14**, a transmission path **16** and a network monitor **18**. The transmitter terminal **12** comprises four optical transmitters **20**, a wavelength multiplexer **22** and optical fibers **24**. Each transmitter **20** has an input **28**, an output **32** and control input **30** for controlling the optical power of the output **32**. The wavelength multiplexer **22** has inputs **34** and an output **36**. Each transmitter output **32** is connected to a respective wavelength multiplexer input **34** by an optical fiber **24**. The wavelength multiplexer output **36** is connected to transmission path **16** by optical fiber **48**. The transmission path **16** comprises optical amplifiers **38** and optical fiber cable **40**. Each optical amplifier **38** has an input **42**, an output **44** and a data output **46** for providing a measurement of the optical signal power at the input **42**. The optical amplifiers **38** are serially connected by optical fiber cable **40**. The receiver terminal **14** comprises a wavelength demultiplexer **50**, four optical receivers **52** and optical fiber **54**. The wavelength demultiplexer **50** has an input **64** and outputs **62**. Each optical receiver **52** has an input **56** and an output **58**. Each receiver input **56** is connected to a respective wavelength demultiplexer output **62** by an optical fiber **54**. The wavelength demultiplexer input **64** is connected to transmission path **16** by optical fiber **68**. The network monitor **18** has inputs **70** and an output **72**. Each network monitor input **70** is connected to a respective optical amplifier data output **46** by network links **74**. The network monitor output **72** is connected to optical transmitter control inputs **30**.

[0014] In operation, information signals **UCI1** to **UCI4** are applied to inputs **28** of optical transmitters **20**. The optical transmitters **20** output optical signals **s1** to **s4** which are light of wavelength $\lambda 1$ to $\lambda 4$ modulated by information signals **UCI1** to **UCI4** respectively. Wavelengths $\lambda 1$ to $\lambda 4$ correspond to channels **c1** to **c4** respectively. **FIG. 2** is a graph of the optical spectrum at the wavelength demultiplexer input **64** showing channels **c1** to **c4** at wavelengths $\lambda 1$ to $\lambda 4$ respectively. The wavelength multiplexer **22** combines the optical signals **s1** to **s4** applied to the multiplexer inputs **34** and outputs a combined optical signal S at the multiplexer output **36**. Combined signal **S** is transmitted to the receiver terminal **14** by transmission path **16**. Each optical amplifier **38** amplifies the signal applied to its input **42** by an amount of gain which is dependent upon wavelength and provides a signal to its output **44** whereby the optical power of the output signal equals the gain times the optical power of the input signal. Since the amount of gain is dependent upon wavelength, each channel of combined optical signal **S** is amplified by a different amount of gain. **FIG. 2** shows the

unequal optical power levels of signals **s1** to **s4** at the wavelength demultiplexer input **64** for equal optical power levels output by the transmitters **20**.

[0015] Examples of optical amplifiers are semiconductor optical amplifiers and rare earth doped fiber amplifiers. Optical amplifiers add noise to the system, typically in the form of amplified spontaneous emission (ASE), so that the optical signal to noise ratio (OSNR) is degraded at each amplifier site. The OSNR is defined as the ratio of signal optical power to the ASE noise power in a reference optical bandwidth. Almost all optical amplifiers exhibit a nonuniform wavelength dependent gain profile, noise profile, and saturation characteristics. These characteristics along with wavelength dependent loss of other components in the system results in unequal OSNRs of the channels for equal transmitter optical power levels.

[0016] Bit error rate (BER) is a typical performance parameter for digital transmission systems such as optical WDM systems. BER can be determined for each channel in a transmission system and is typically related to OSNR for optical transmission systems. The BER of the channels may be equalized by adjusting the optical power level of the transmitters such that OSNRs at the receiver terminal are equalized. However, if the signals transmitted by their respective channels have different bit rates, signal qualities, or amounts of distortion, then these factors should be taken into account in combination with the OSNRs as part of the equalization process.

[0017] The method of equalizing the performance of the channels at the wavelength demultiplexer input **64** includes the steps of measuring the optical power of the signals **s1** to **s4** at the optical amplifier inputs **42**, estimating the relative BER performance of the channels at the wavelength demultiplexer input **64**, and adjusting the optical power of the transmitters **20** to equalize the performance. In order to estimate the BER performance, the noise figures (*F*) for each amplifier **38** in the transmission path **16** must be known whereby noise figure F^i corresponds to the amount of noise, such as ASE noise, generated by an amplifier at the ith channel wavelength. The BER performance of a channel operating at wavelength λi is related to the OSNR of the channel which can be estimated from:

$$\textbf{EQ. 1:} \qquad \mathrm{OSNR}(\lambda i) = \frac{1}{h\nu Bo\left(\sum_{j=1}^{M} \frac{1}{F^i_j\, P^i_j}\right)}$$

where j is taken over all optical amplifiers in the transmission path **16**, Bo is the optical bandwidth on which the OSNR is to be estimated, $h\nu$ is the photon energy at wavelength λi, P^i_j is the optical power of the signal transmitted over the ith channel measured at the input of the jth amplifier, and F^i_j is the noise figure of the jth amplifier at channel i. To equalize the BER performance of the channels relative to any one of the channels selected as the reference channel (ref), the optical power of the transmitters are adjusted whereby the amount of adjustment (Xi) in decibels (dB) of the ith transmitter is calculated from the equation:

$$\textbf{EQ. 2:} \qquad X_i = 10\,\mathrm{LOG}_{10}\left(\frac{\sum_{j=1}^{M} \frac{1}{F^{ref}_j\, P^{ref}_j}}{\sum_{j=1}^{M} \frac{1}{F^i_j\, P^i_j}}\right)$$

where j is taken over all optical amplifiers in the transmission path **16**.

[0018] It should be recognized that it is not necessary to estimate the OSNRs to equalize the channels since it is EQ. 2 that is used to calculate the amount of transmitter optical power adjustment that is required to equalize the performance of the channels. Therefore the method of equalizing the performance of the channels at the receiver inputs **56** need only include the steps of measuring the optical power of the signals **s1** to **s4** at the optical amplifier inputs **42**, and adjusting the optical power of the transmitters **20** to equalize the performance of the channels whereby the amount of adjustment is calculated from EQ.2.

[0019] Furthermore, it should be recognized that if the amplifier noise figures (F) are constant over all channel wavelengths and over all amplifiers, which is typically a good approximation for channels spaced closely in wavelength and for similar amplifiers, then the noise figures F^i_j can be factored out of EQ. 2. The amount of transmitter optical power adjustment is then dependent upon the sum of the reciprocal of the signal optical power measurements taken over the transmission path of the signal relative to the sum of the reciprocal of the reference channel signal optical power

measurements taken over the transmission path of the reference channel signal. Therefore the method of equalizing the performance of the channels at the wavelength demultiplexer input 64 need only include the steps of measuring the optical power of the signals **s1** to **s4** at the optical amplifier inputs **42**, and adjusting the optical power of the transmitters **20** to equalize the performance of the channels whereby the amount of adjustment is dependent upon the sum of the reciprocal of the signal optical power measurements relative to the sum of the reciprocal of the reference signal optical power measurements.

[0020] The method of equalizing the performance of the channels has been described so far with regard to equalizing the performance at the wavelength demultiplexer input **64.** However, the method can be used to equalize two or more channels relative to one another at any location in the transmission path of the channels that is downstream of an optical amplifier **38** in the transmission path. In that case, optical power measurements of the signals are taken at the inputs **42** of the optical amplifiers **38** that are upstream of the location where performance is to be equalized and the transmitters are adjusted using the optical power measurements in accordance with the previously described method. Furthermore even if one channel is transmitted over a path that has sections of the path that are physically separate from the other path, the performance of the channels can be equalized at a location that is physically common to both paths by using the described method. The location at which the equalization of performance is to be effective must be downstream of an amplifier in one path and downstream of an amplifier in the other path. The optical power measurements of the signals are taken at the inputs **42** of the optical amplifiers **38** that are upstream of the location where performance is to be equalized and the transmitters are adjusted using the optical power measurements in accordance with the previously described method. Moreover, the method can be performed dynamically and can therefore be responsive to changes in channel performance that could for example be due to changes in the WDM system caused by fault conditions or by network reconfiguration.

[0021] As mentioned earlier, if the signals transmitted by their respective channels have different bit rates, then a bit rate dependent offset should be used when adjusting the optical power of the transmitters of those channels for the purpose of equalizing channel performance. For example, if signal **s1** operates at twice the bit rate of signal **s2.** then signal **s1** will have a noise bandwidth approximately equal to twice the noise bandwidth of **s2**. Since BER depends on the square root of the noise bandwidth, signal **s1** would require an OSNR about 1.5 dB higher than signal **s2** to have an equal BER performance. The amount of bit rate dependent offset (Y) to be added to a transmitter adjustment (X) calculated from EQ. 2, for adjusting the transmitter of signal **s1** at channel **c1** to equalize its channel performance relative to a reference a channel **c2** carrying a signal **s2** of bit rate different than signal **s1**, is calculated from EQ. 3.

EQ. 3:

$$Y = 10\,\mathrm{LOG}_{10}\left[\left(\frac{\text{bit rate of } s1}{\text{bit rate of } s2}\right)^{1/2}\right]$$

Therefore, if channels carry signals of different bit rates then the method of equalizing the performance of the channels includes the step of first adding an offset that is dependent upon the bit rate of the channel signal relative to the bit rate of the reference channel signal to the transmitter optical power adjustment calculated from EQ. 2 to obtain a resultant amount (Z) of transmitter optical power adjustment. The resultant amount (Z) of transmitter optical power adjustment is calculated from the equation:

EQ. 4: $Z=X+Y$

where Z is given in decibels, X is calculated from EQ. 2 and Y is calculated from EQ. 3.

[0022] The method of equalizing the channels includes repeating the aforementioned steps of the method until the transmitter adjustment amount calculated from EQ. 2, and in combination with the offset calculated from EQ. 3 when applicable, is less than a predetermined amount. For example, the amount of adjustment could be the minimum adjustment amount of the transmitter optical power.

[0023] **FIG. 3** is a block diagram of WDM system that includes an add-drop multiplexer (ADM) **130**. The ADM **130** has optical inputs **132** and **134**, and optical outputs **136** and **138**. Input **132** is connected to the output **44** of an optical amplifier **38** labelled as **OA2**. ADM output **136** is connected to the input **56** of an optical receiver **52** labelled as **Rx5**. The ADM input **134** is connected to the output **32** of an optical transmitter **20** labelled as **Tx5**. The output **138** of ADM **130** is connected to the input **42** of an optical amplifier **38** labelled as **OA3**. The control input **30** of the optical transmitter **Tx5** is connected to an output **72** of the network monitor **18**.

[0024] Referring to **FIG. 3**, in operation the ADM **130** extracts channel **c4**, transmitting signal **s4**, from the network

and directs it to an alternative receiver **Rx5**. The ADM **130**, inserts a new signal **s5** into the WDM system at a channel wavelength λ**4** which is the same wavelength as the extracted channel **c4**. The performance of the channels can be equalized at the wavelength demultiplexer input **64** in accordance with the method previously described wherein the optical power of signal **s5** is measured at the inputs **42** of optical amplifiers **OA3** and **OA4** and the optical power of signals **s1**, **s2** and **s3** are measured at the inputs **42** of amplifiers **OA1** to **OA4**. The performance of the channels are equalized by using EQ. 2, and in combination with EQ. 3 in the case of unequal bit rates, to calculate the amount of transmitter adjustment necessary to equalize each channel relative to a reference channel, the reference channel being any channel chosen from channels **c1** to **c4**. The performance of inserted channel **c4** is equalized by adjusting the optical power of transmitter **Tx5**. The amount of adjustment to transmitter **Tx5** is dependent upon the optical power measurements made on signal **s5** at the inputs **42** of amplifiers **OA3** and **OA4**. Optical amplifiers **OA3** and **OA4** are upstream of the wavelength demultiplexer input **64** which is the location in the transmission path where the performance of channels **c1** to **c4** is to be equalized. The performance of channels **c1**, **c2** and **c3** are equalized relative to channel **c4** by adjusting the optical power of transmitters **Tx1**, **Tx2** and **Tx3** respectively. The transmitters **Tx1** to **Tx3** are adjusted in dependence upon the optical power measurements made on signals **s1** to **s3** at the inputs **42** of optical amplifiers **OA1** to **OA4**. Optical amplifiers **OA1** to **OA4** are upstream of the wavelength demultiplexer input **64** which is the location in the transmission path where the performance of channels **c1** to **c4** is to be equalized. Therefore the method of equalizing the performance of channels in a WDM system having an add-drop multiplexer includes the step of adjusting the optical power of the transmitters of the channels by an amount dependent upon the optical power measurements of the signals taken at the inputs of the optical amplifiers along the respective transmission paths of the signals.

[0025] **FIG. 4** illustrates a WDM system with an ADM **130** that extracts two channels **c3** and **c4**, transmitting signals **s3** and **s4** respectively, and directs them to two receivers **Rx5** and **Rx6**. The method of equalizing the performance of the channels **c3** and **c4** at the inputs of receivers **Rx5** and **Rx6** includes adjusting the optical power of transmitters **Tx3** and **Tx4** from optical power measurements of signals **s3** and **s4** made at the inputs of optical amplifiers **OA1** and **OA2**. The amount of adjustment to transmitters **Tx3** and **Tx4** is calculated using EQ. 2, and in combination with EQ. 3 when applicable as previously described. Referring again to **FIG. 4**, there is shown two signals **s5** and **s6** inserted by the ADM **130** at channel wavelengths λ**3** and λ**4** corresponding to channels **c3** and **c4**. The performance of inserted channels **c3** and **c4** can be equalized with respect to each other and the performance of channels **c1** and **c2** at the wavelength demultiplexer input **64** in accordance with the previously described method. The method of equalizing the performance of the channels **c1** to **c4** includes the step of adjusting the optical power of transmitters, **Tx1**, **Tx2**, **Tx5** and **Tx6**, by an amount dependent upon the optical power measurements of signals **s1**, **s2**, **s5** and **s6** taken at the inputs of the optical amplifiers in the respective transmission paths of the signals. Specifically, the amount of optical power adjustment for transmitters **Tx1** and **Tx2** is calculated from EQ. 2, and in combination with EQ. 3 when applicable, using optical power measurements of signals **s1** and **s2** taken at the inputs **42** of amplifiers **OA1** to **OA4**. The amount of optical power adjustment for transmitters **Tx5** and **Tx6** is calculated in the same way from optical power measurements of signals **s5** and **s6** taken at the inputs **42** of amplifiers **OA3** and **OA4**. The reference channel for equalizing the performance of channels **c1** to **c4** may be any one of channels **c1** to **c4**.

[0026] With reference to **FIG. 1**, the network monitor **18** in the WDM system **10** provides the means for equalizing performance of channels in a WDM system according to the previously described method. The optical power measurements of signals **s1** to **s4** at inputs **42** of the optical amplifiers **38** are transmitted to the network monitor **18** over data links **74** to network monitor inputs **70**. The network monitor **18** has a receiving means for receiving the optical power measurements and a storing means for storing the optical power measurements. The network monitor **18** has a calculating means for calculating OSNRs of the channels at the wavelength demultiplexer input **64** using EQ. 1 and the stored optical power measurements. The network monitor **18** has an adjustment calculating means for calculating the amount of adjustment to the optical power of transmitters **Tx1** to **Tx4** using EQ. 2, and in combination with EQ. 3 in case of different bit rates. The network monitor may have a selection means for selecting a reference channel for the purpose of calculating the optical power adjustments of the transmitters **20**, or alternatively the reference channel may be predetermined. The network monitor has a communicating means for communicating the transmitter optical power adjustments to the transmitters **20**. The transmitter optical power adjustments are communicated from the output **72** of the network monitor **18**, through the data link **74** to the data input **30** of the transmitters **20**. The network monitor may also have a repeating means for repeating the steps of receiving and storing the optical power measurements, calculating transmitter optical power adjustments, and communicating the adjustments to the transmitters **20** until the calculated optical power adjustments are less than the minimum optical power adjustment amount of the transmitters **20**, or some other predetermined amount. With reference to **FIG. 3** and the corresponding method previously described, the adjustment calculating means includes a means for calculating transmitter optical power adjustments for equalizing the performance of a channel inserted by an add-drop multiplexer into the WDM system relative to another channel in the system. With reference to **FIG. 4** and the corresponding method previously described, the adjustment calculating means includes a means for calculating transmitter optical power adjustments for equalizing the performance of chan-

nels extracted by an add-drop multiplexer relative to one another.

[0027] Other embodiments are possible and changes may be made to the disclosed embodiments without departing from the scope of the invention. The detailed description provided does not limit the invention, instead, the scope of the invention is defined only by the appended claims.

Claims

1. A method of equalizing performance of a first channel transmitting a first signal from a first transmitter along a first transmission path with respect to performance of a second channel transmitting a second signal from a second transmitter along a second transmission path the equalization being effective at a predetermined location in an optical wavelength division multiplexed system and the location being downstream of an optical amplifier in the first path and downstream of an optical amplifier in the second path, the method comprising:

   measuring the optical power of the first signal and the second signal at the inputs of each optical amplifier that is upstream of said location; and
   adjusting the optical power of the first transmitter by an amount dependent upon the sum of the reciprocal of the first signal optical power measurements relative to the sum of the reciprocal of the second signal optical power measurements.

2. A method as defined in claim 1, wherein the step of adjusting the optical power of the first transmitter comprises first adding an offset to said amount of transmitter adjustment to obtain a resultant amount of transmitter adjustment and then adjusting the optical power of the first transmitter by the resultant amount, said offset being dependent upon the difference between the bit rate of the first signal and the second signal.

3. A method as defined in claim 1, wherein the step of adjusting the optical power of the first transmitter comprises:

   predefining a noise figure for each said optical amplifier; and
   adjusting the first transmitter by an amount in dependence upon the sum of the reciprocal products of the noise figure and the respective signal optical power measurement taken at each optical amplifier along said paths.

4. A method as defined in claim 1, wherein the method comprises repeating the steps defined in claim 1 until said amount of transmitter adjustment is less than a predetermined amount.

5. A method as defined in claim 2, wherein the step of adjusting the optical power of the first transmitter comprises:

   predefining a noise figure for each said optical amplifier; and
   adjusting the optical power of the first transmitter in dependence upon the sum of the reciprocal products of the noise figure and the respective signal optical power measurement taken at each optical amplifier along said paths.

6. A method as defined in claim 5, wherein the method comprises repeating the steps defined in claim 5 until the resultant amount of transmitter optical power adjustment is less than a predetermined amount.

7. A method as defined in claim 6, wherein said amount of transmitter adjustment is calculated from the eauation:

$$X = 10\mathrm{LOG}_{10}\left(\frac{\sum_{k=1}^{N}\frac{1}{F^2_k P^2_k}}{\sum_{j=1}^{M}\frac{1}{F^1_j P^1_j}}\right)$$

   where j corresponds to the jth optical amplifier of M optical amplifiers upstream of said location in the transmission path of the first signal, F^1_j is the noise figure of the jth optical amplifier upstream of said location in the transmission path of the first signal, p^1_j is the optical power of the first signal measured at the input of the jth optical

amplifier upstream of said location in the transmission path of the first signal, k corresponds to the kth optical amplifier of N optical amplifiers upstream of said location in the transmission path of the second signal. F_k^2 is the noise figure of the kth optical amplifier upstream of said location in the transmission path of the second signal, P_k^2 is the optical power of the second signal measured at the input of the kth optical amplifier upstream of said location in the transmission path of the second signal,

8. A method as defined in claim 7, wherein said offset is calculated from the equation:

$$Y = 10\mathrm{LOG}_{10}\left[\left(\frac{\text{bit rate of } s1}{\text{bit rate of } s2}\right)^{1/2}\right].$$

9. An apparatus for equalizing performance of a first channel transmitting a first signal from a first transmitter along a first transmission path with respect to performance of a second channel transmitting a second signal from a second transmitter along a second transmission path the equalization being effective at a predetermined location in an optical wavelength division multiplexed system and the location being downstream of an optical amplifier in the first path and downstream of an optical amplifier in the second path, the apparatus comprising:

   a receiving means for receiving optical power measurements of said signals taken at the inputs of each optical amplifier that is upstream of said location;
   a storing means for storing said optical power measurements:
   a calculating means for calculating an amount of transmitter optical power adjustment of the first transmitter from the optical power measurements; and
   a communicating means for communicating the amount of transmitter optical power adjustment to the first transmitter.

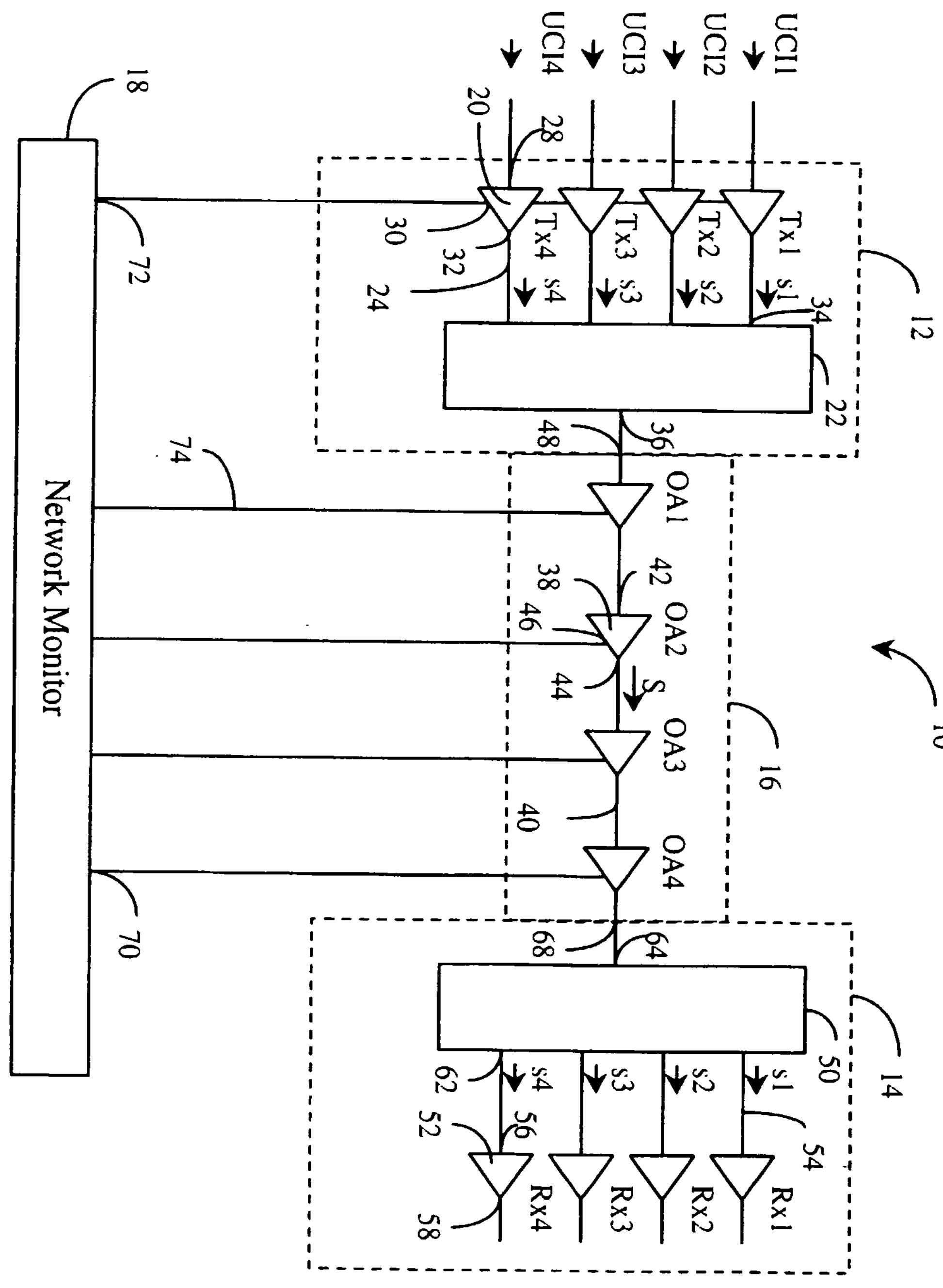
10. An apparatus as defined in claim 9, comprising an offset calculating means for calculating an offset to be added to the amount of transmitter optical power adjustment to obtain a resultant amount of transmitter adjustment for adjusting the optical power of the first transmitter, said offset being dependent upon the difference between the bit rate of the first signal and the second signal.

11. An apparatus as defined in claim 10, comprising a repeating means for repeating the steps of receiving and storing the optical power measurements, calculating the amount of transmitter optical power adjustment, calculating the offset to be added to the amount of transmitter optical power adjustment and communicating the resultant amount of transmitter optical power adjustment to the first transmitter, until the resultant amount of transmitter optical power adjustment is less than a predetermined amount.

12. An apparatus as defined in claim 11, wherein the calculating means comprises a means for calculating the amount of transmitter optical power adjustment when the first channel is one that has been inserted by an add-drop multiplexer into the wavelength division multiplex system.

13. An apparatus as defined in claim 12, wherein the calculating means comprises a means for calculating the amount of transmitter optical power adjustment for equalizing the performance of said channels relative to one another when said channels are ones that have been extracted from the optical wavelength division multiplex system by an add-drop multiplexer.

14. An apparatus as defined in claim 13, comprising a selection means for selecting the second channel.


UCI1
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Network Monitor
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44
46
48
50
52
54
56
58
62
64
68
70
72
74

FIG. 1

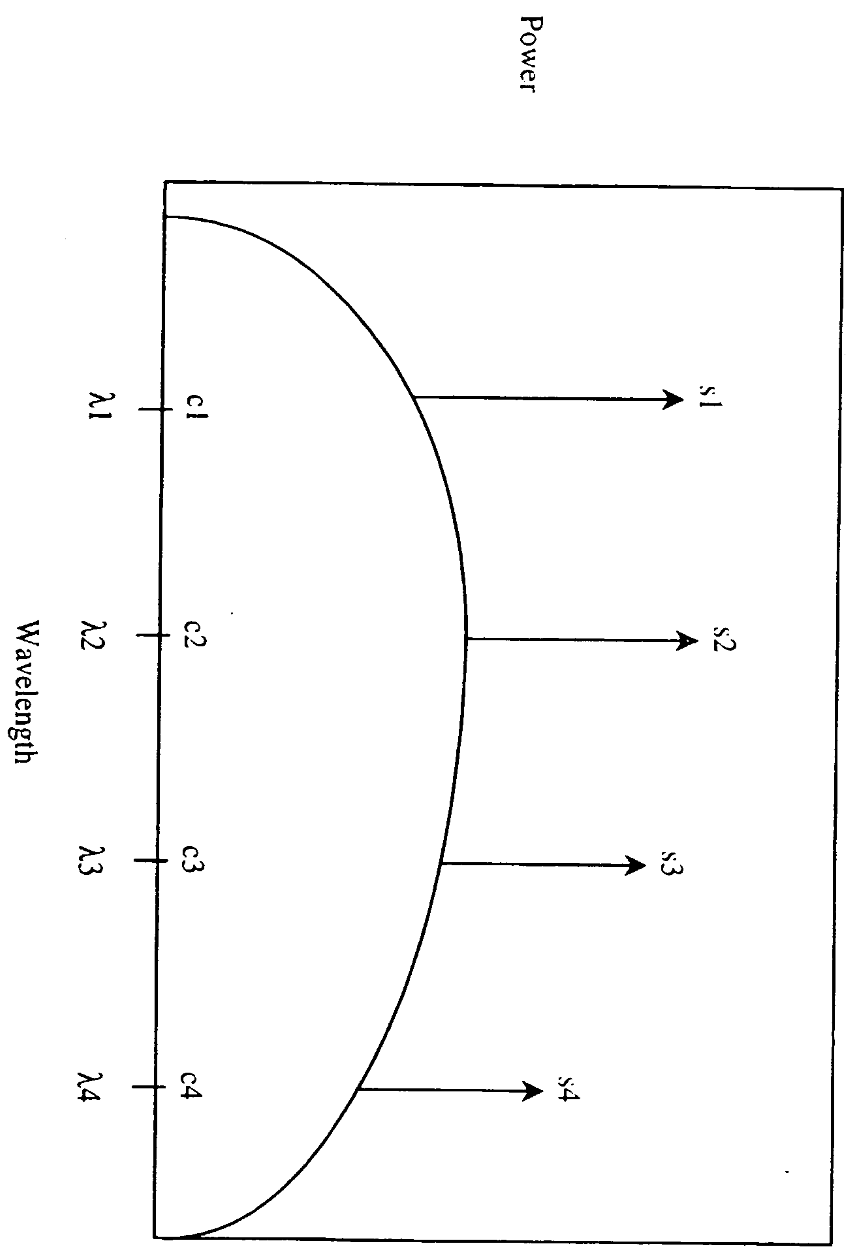


FIG. 2

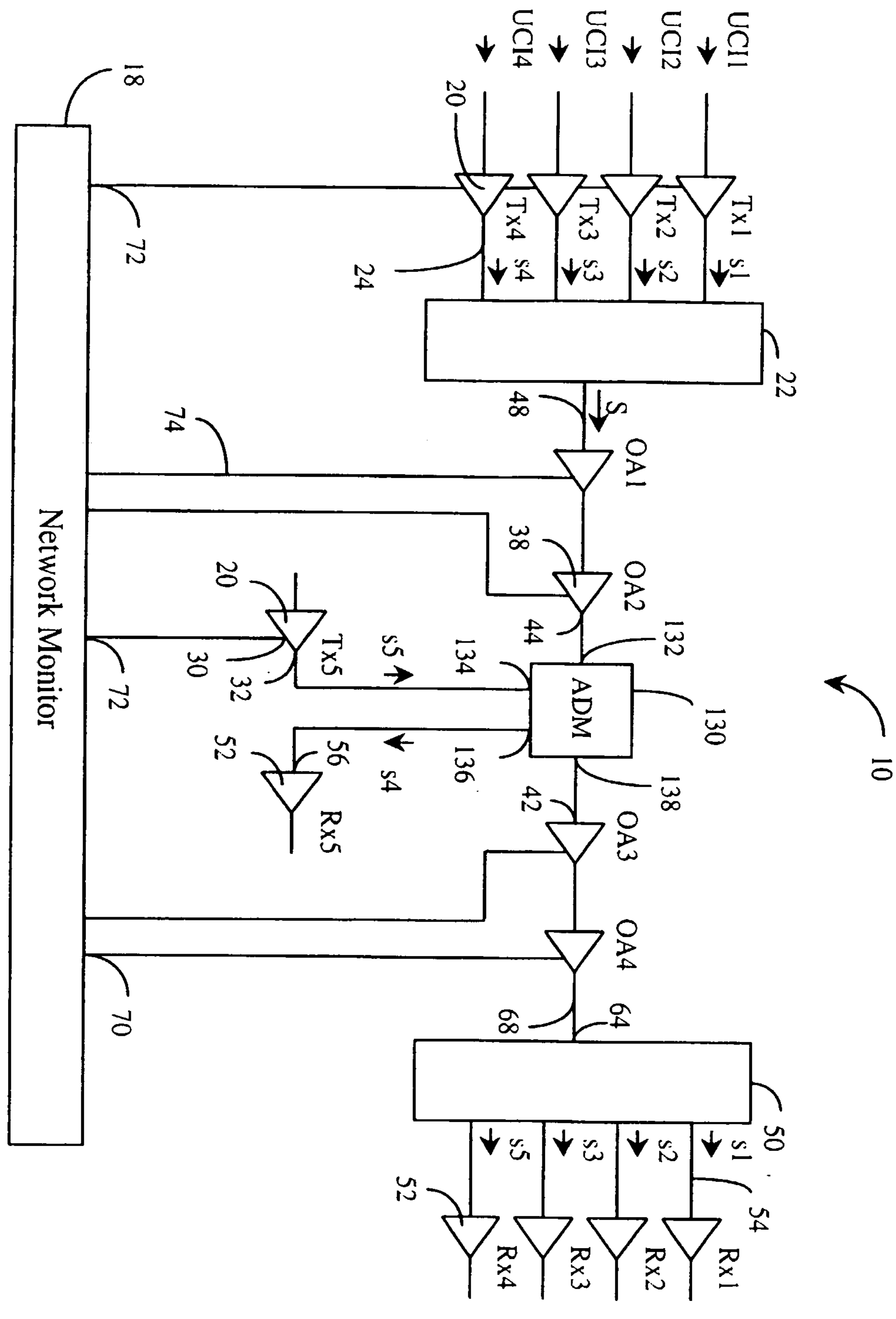
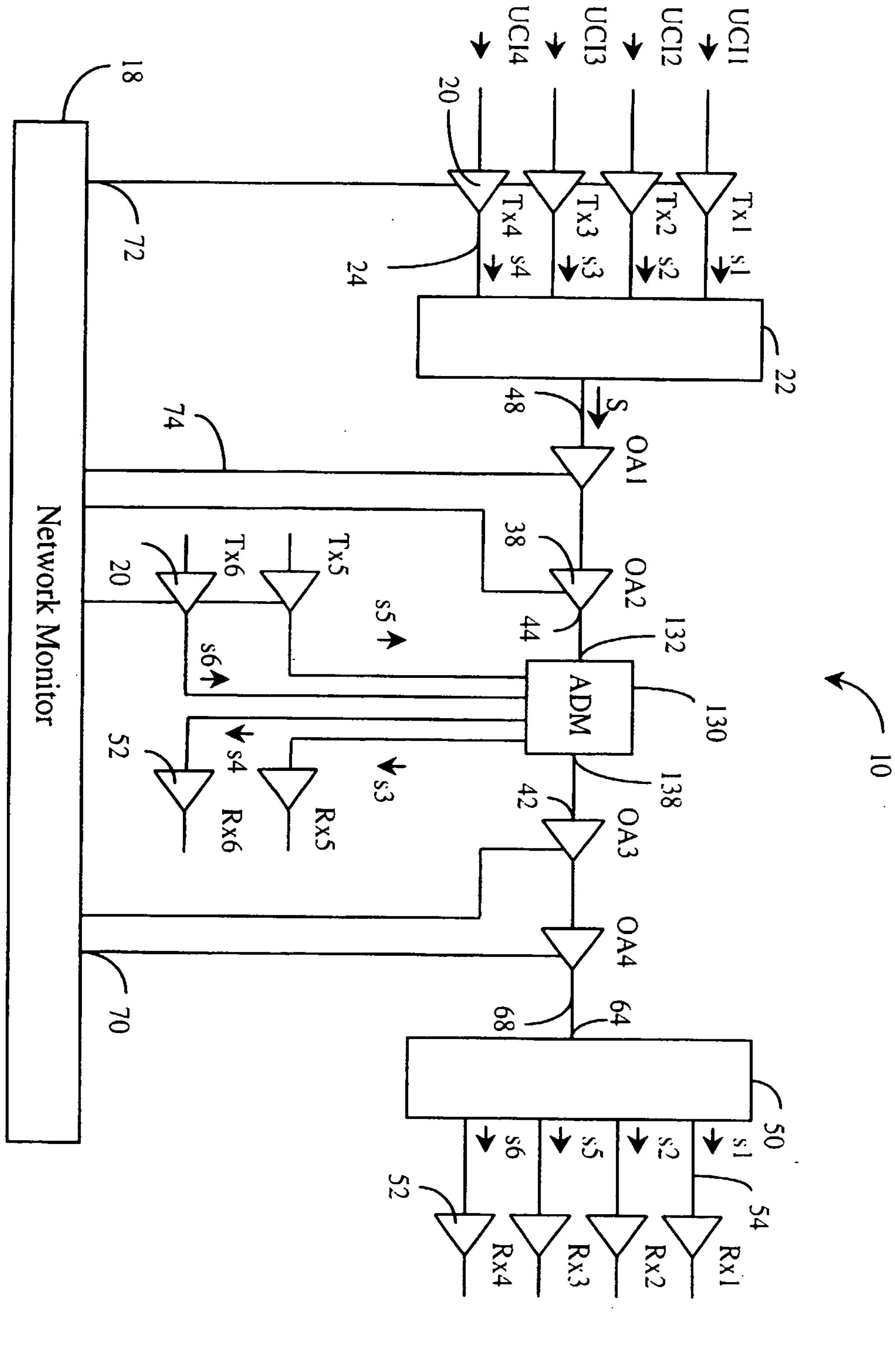

10
UCI1
UCI2
UCI3
UCI4
Tx1
Tx2
Tx3
Tx4
s1
s2
s3
s4
20
24
22
18
72
48
S
74
OA1
38
OA2
Network Monitor
132
130
ADM
134
s5
Tx5
20
30
32
72
136
s4
56
52
Rx5
138
42
OA3
OA4
70
68
64
50
s1
s2
s3
s5
54
52
Rx1
Rx2
Rx3
Rx4

FIG. 3


UCI1
UCI2
UCI3
UCI4
Tx1
Tx2
Tx3
Tx4
s1
s2
s3
s4
S
OA1
OA2
OA3
OA4
ADM
Tx5
Tx6
Rx5
Rx6
s5
s6
s3
s4
Rx1
Rx2
Rx3
Rx4
s1
s2
s5
s6
Network Monitor
10
18
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24
38
42
44
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68
70
72
74
130
132
138

FIG. 4